Amendments to the Drawings:

FIG. 5 was objected to as "depicting plural (two) communication elements 450" with only one element being annotated or identified. In this regard, the Applicants submit that the non-annotated or non-identified "element" indicated in the Office Action is merely intended to indicate that the computer device 120 / control system 400 may be a "laptop" type computer device that can be closed (illustrating a connector portion 720), or opened (to reveal a keypad 140 and display 160). That is, the non-annotated or non-identified "element" is **not** intended to indicate a communication element 450. In this regard, FIG. 5 has been amended to illustrate the non-annotated or non-identified "element," as well as the opened computer device 120 / control system 400 in phantom. In this regard, the Specification has also been amended, as otherwise detailed herein, to indicate the amendments to FIG. 5. The Applicants submit that these amendments find support, for example, in FIG. 5 of the Drawings and from Page 6, line 28 through Page 7, line 13 of the Specification, and no new matter has been added. The Applicants thus request withdrawal of this objection.

REMARKS/ARGUMENTS

In light of the following remarks, reexamination and reconsideration of this application, withdrawal of the rejections, and formal notification of the allowability of all claims as presented are earnestly solicited. As detailed in the Office Action mailed September 22, 2005, Claims 1-42 are pending, wherein Claims 1-7, 9, 14, 15, 17-23, 25, 28, 29, 31-38, 40, and 42 have been rejected and Claims 8, 10-13, 16, 24, 26, 27, 30, 39, and 41 have been objected to. In response, the Applicants traverse the rejections. It is believed that the claims define patentable subject matter over the prior art cited in the Office Action and notice to such effect is requested at the Examiner's earliest convenience.

Information Disclosure Statement

The Information Disclosure Statement filed 2-April-2004 was objected to as failing to comply with 37 CFR 1.98(a)(2) regarding a legible copy. In response, a legible copy of Oloufa, A., "Quality Control of Asphalt Compaction Using GPS-Based System Architecture," IEEE Robotics & Automation Magazine, 2002, pp. 29-35, is again submitted by the Applicants. The Applicants thus request withdrawal of this objection and consideration of this reference.

Claim Rejections – 35 U.S.C. §102

Claims 1, 2, 9, 14, 15, 17-19, 25, 28, 29, 31-33, 40, and 42 were rejected as being anticipated by U.S. Patent No. 5,952,561 to Jaselskis *et al.* In response, the Applicants traverse the rejections.

The Jaselskis '561 patent is directed to a real time differential asphalt pavement quality sensor for measuring asphalt density in real time using a differential approach. Two sensors, one in the front of a roller and another behind the roller, measure reflected signals from the asphalt. The difference between the reflected signals provides an indication of the optimal compaction and density of the asphalt pavement. The change in variance over successive passes determines when the optimal level of compaction has been reached. FIG. 3 of the Jaselskis '561 patent shows an apparatus for field testing on test strips of asphalt pavement. The electronic equipment

used for the testing consisted of a Hewlett Packard (HP) 8350B sweep oscillator, an HP 8410A network analyzer, an HP 8411A harmonic frequency converter, an Apex personal computer, a motor-driven linear positioner, a Narda Model 640 standard gain horn antenna, and other components such as isolators, directional couplers, waveguides, and cables. As shown in FIG. 3, an antenna 40 and linear scanner 41 were mounted on a motor-driven positioner 42 driven by a stepper motor 44 to obtain measurements at multiple locations along a particular strip of asphalt 46. **A measurement set began with the sweep oscillator generating signals from 8 GHz to 12 GHz in increments of 0.4 GHz. The values for the reflected signals at these frequencies were stored in a data set on the hard drive of computer 48.** The positioner 42 then moved the antenna 40 forward by 2 cm and the next data set was obtained. The procedure was repeated until 40 data sets were taken. A variety of measurement sets was taken using three different antenna positions (10 cm, 12.5 cm, and 15 cm above the asphalt surface) and two separate angles of incidence (0° and 10°). Various other sensor configurations are disclosed by the Jaselskis '561 patent, wherein **a common aspect of such configurations is the collection and processing of the collected data with a computer**.

In contrast, independent Claim 1 now particularly recites a system adapted to determine a property of a paving-related material, wherein such a system comprises a measuring device for selectively and directly measuring the property of the paving-related material. A computer device is capable of executing a software program product and communicating with the measuring device, wherein **the computer device is configured to direct the measuring device to directly measure the property of the paving-related material according to a parameter determined by the software program product**, and to receive data comprising the measured property of the paving-related material from the measuring device. A communication element is operably engaged between the measuring device and the computer device so as to allow communication therebetween such that **the measuring device directly measures the property of the paving-related material in response to the direction of the computer device received via the communication element**. The communication element is configured to allow the computer device to be spaced apart from the measuring device, thereby allowing the computer

device to be prepared, to include the parameter and to manipulate the data, in spaced apart relation with respect to the measuring device.

Independent Claim 18 recites a method of determining a property of a paving-related material, wherein such a method comprises **preparing a computer device to execute a software program product for directing a measuring device to directly measure the property of the paving-related material, according to a parameter determined by the software program product**, and to receive data comprising the measured property of the paving-related material from the measuring device. After executing the software program product, **the executed software program product is communicated from the computer device to the measuring device via a communication element operably engaged therebetween such that the measuring device directly measures the property of the paving-related material in response thereto**. The communication element is configured to allow the computer device to be spaced apart from the measuring device such that the computer device can be prepared, in spaced apart relation with respect to the measuring device, to include the parameter and to manipulate the data.

Independent Claim 32 recites a system adapted to cooperate with a measuring device to selectively and directly measure a property of a paving-related material, wherein such a system comprises a computer device capable of executing a software program product and communicating with the measuring device. **The computer device is configured to direct the measuring device to directly measure the property of the paving-related material according to a parameter determined by the software program product**, and to receive data comprising the measured property of the paving-related material from the measuring device. A communication element is operably engaged between the measuring device and the computer device so as to allow communication therebetween such that **the measuring device directly measures the property of the paving-related material in response to the direction of the computer device via the communication element**. The communication element is configured to allow the computer device to be spaced apart from the measuring device, thereby allowing the computer device to be prepared, to include the parameter and to manipulate the data, in spaced apart relation with respect to the measuring device.

Thus, each of Claims 1, 18, and 32 particularly requires that a computer device be capable of communicating with a measuring device configured to directly measure the property of the paving-related material, in order to **direct the measuring device to measure the property of the paving-related material according to a parameter determined thereby**. That is, **the computer device is configured to execute a software program and then direct the measuring device to perform the measurement according to a parameter determined by the executed software**. The computer device then receives the measurement data from the measuring device for processing. Further, a communication element is disposed between the measuring device and the computer device to allow the computer device to provide the measurement directive to the measuring device for conducting the measurement. In this regard, the Applicants submit that, in the embodiments disclosed by the Jaselskis '561 patent, **the computer is only used for gathering and processing the measurement data generated by the measuring apparatus**. That is, **the Jaselskis '561 patent *does not* teach or suggest a computer device configured to provide a measurement parameter to a measuring device, so as to direct the measuring device to perform a measurement according to that parameter, wherein the parameter is determined by software executed by the computer device**.

Accordingly, the Applicants submit that there is **no identity** between Claims 1, 18, and 32, now pending, and the disclosure of the Jaselskis '561 patent. As such, the Applicants further submit that the present invention, as now defined by Claims 1, 18, and 32, as well as Claims 2, 9, 14, 15, 17, 19, 25, 28, 29, 31, 33, 40, and 42 which depend therefrom, **is patentable** over the Jaselskis '561 patent. As such, the Applicants respectfully request withdrawal of these rejections.

Claim Rejections – 35 U.S.C. §103

Claims 3-7, 20-23, and 34-38 were also rejected in the Office Action as being obvious over the Jaselskis '561 patent in view of U.S. Patent No. 5,132,871 to Densham *et al.* As previously discussed, Claim 1, upon which Claims 3-7 depend, Claim 18, upon which Claims 20-23 depend, and Claim 32, upon which Claims 34-38 depend, are not anticipated by the Jaselskis '561 patent. As such, the Applicants submit that Claims 3-7, 20-23, and 34-38, which

depend either directly or indirectly from Claims 1, 18, or 32, are patentable over the Jaselskis '561 patent cited in the Office Action. As such, the Applicants respectfully request withdrawal of these rejections.

Conclusion

In summary, the Jaselskis '561 and Densham '871 patents, either separately or in combination, **do not** teach or suggest the embodiments of the present invention as now claimed in Claims 1, 18, and 32. Accordingly, in view of these differences between the Applicants' invention and the Jaselskis '561 and Densham '871 patents, it is submitted that the present invention, as defined by the pending claims, is patentable over the prior art cited in the Office Action. As such, Claims 1-42 are believed to be in condition for immediate allowance.

In conclusion, for the reasons set forth above, the Applicant submits that all claims now pending are in condition for immediate allowance. Accordingly, notice to such effect is respectfully requested at the Examiner's earliest opportunity.

It is not believed that extensions of time or fees for net addition of claims are required, beyond those that may otherwise be provided for in documents accompanying this paper. However, in the event that additional extensions of time are necessary to allow consideration of this paper, such extensions are hereby petitioned under 37 CFR § 1.136(a), and any fee required therefore (including fees for net addition of claims) is hereby authorized to be charged to Deposit Account No. 16-0605.

Appl. No.: 10/817,169
Amdt. dated 04/11/2006
Reply to Office action of January 11, 2006

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Date of Deposit April 11, 2006

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Global-Positioning Systems Allow Tracking of Remote Paving Compactors with High Accuracy

Quality Control of Asphalt Compaction Using GPS-Based System Architecture

BY AMR A. OLOUFA

Compaction is the process of reducing the air voids content of asphalt pavement between solid particles. It involves the packing and orientation of the solid particles into a more dense and effective particle arrangement [1].

On asphalt-paved roads, highway and transportation agencies devote considerable resources to the quality control of the paving process to ensure that the constructed roadway has a smooth surface that is capable of accommodating traffic loads designed for it. Paving surfaces that suffer from low density are prone to cracking that can cause accidents and an uncomfortable ride and lead to the eventual destruction of the entire roadway surface.

Asphalt is transported by trucks and dumped in a paver machine. The paver spreads the asphalt material on the surface of the roadway where it is closely followed by one or more compaction machines. These machines may have tires, metallic drums, or both. Some compactors also have a vibrating mass, with a controllable frequency and amplitude, that vibrates the underlying asphalt during the course of compaction. In a roadway project, the contractor prepares a test strip that is rolled several times by compaction machinery until the required density is achieved [2], [3]. The number of passes that the compaction machinery accomplishes is referred to as the number of coverages of these compactors.

While the desired outcome to directly measure asphalt density after compaction, all available nondestructive methods for asphalt density offer a correlation to this density, rather than a direct assessment of it. This is true for current popular methods, such as nuclear density gauges, which offer a correlation to the actual asphalt density only at select locations on the asphalt mat where the test was performed.

When other conditions, such as roller frequency, wheel load, and compactor speed, are the same, the density of asphalt pavement is dependent on the number of coverages of the compactor. It is also worth mentioning that, if the asphalt mat is compacted with less than the determined number of passes, there may be a large volume of air voids leading to a low density. On the other hand, if the mat is overly compacted, the aggregates will be crushed further, and the attributes of the mix will change, increasing voids and leading to a reduction in density. Also, if the optimum amount of air voids is reduced,

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this would lead to reduction in strength as the mix has no ability to expand and contract in response to temperature and humidity changes [4].

However, in the compaction process, the number of passes made by compactors is hard to monitor. Fig. 1 shows the results of observations made at 20 locations in a 2-mi stretch of pavement that was rolled with a 12-ton three-wheel roller [5]. This figure shows that two areas in a pavement, the join and edge, tend to receive less compaction than the rest of the cross section.

The system must not only be capable of tracking multiple compactors, it must also be able to display to all compactor operators the total number of coverages achieved over the roadway surface.

For this reason, monitoring the exact number of coverages over the entire surface of the pavement mat is needed. To monitor the number of coverages of a moving vehicle, the precise location of that moving vehicle needs to be known at all times. The continuous monitoring of positions is available through both laser- and satellite-based systems. For this research, continuous positioning through a global-positioning system (GPS) was utilized.

Introduction to GPS Applications

The GPS system is owned by the U.S. Department of Defense and is composed of 24 satellites and ground monitoring and control systems. The GPS receiver is a passive device that receives signals from orbiting satellites. With at least three satellites, the receiver can triangulate its two-dimensional (2-D) position and altitude anywhere on the surface of the earth. In reality, however, the receiver also needs a fourth satellite to resolve for time ambiguities [6].

Signals are broadcast from satellites on two frequencies (L1 and L2). Ranges are derived from the measured travel time of two codes modulated onto these frequencies. The first code is the coarse acquisition code (C/A) and is available for civilian use. The second code is the precision code (P-code), which is reserved for the U.S. military and other authorized users. To ensure against hostile use of this technology, the military degrades the L1 frequency through the introduction of a random error [selective availability (SA)].

GPS technology is relatively inexpensive, but the accuracy of uncorrected positions is about 60 m, which is insufficient for this application. However, through the use of differential GPS, accuracy can be improved to less than 2 cm, which is enough to meet the accuracy requirements of this research.

The idea behind differential GPS (DGPS) is simple [7]. If two receivers are used where one receiver is static, both receivers should suffer from the same error in positioning, especially if both receivers are using the same satellites and are relatively close to each other. However, if one of these receivers is static—therefore, is not moving—this error can be determined and used to correct the error in the other receiver. These errors can be corrected after the positioning data is developed (i.e., post processing), or the error can be transmitted in real time via radio links to the rover (moving unit) where the errors are corrected instantly.

Achieving high positional accuracy requirements is important for this research. Dual frequency GPS devices (i.e., utilizing both L1 and L2) were the sole devices capable of providing compactor positioning. These devices are relatively expensive

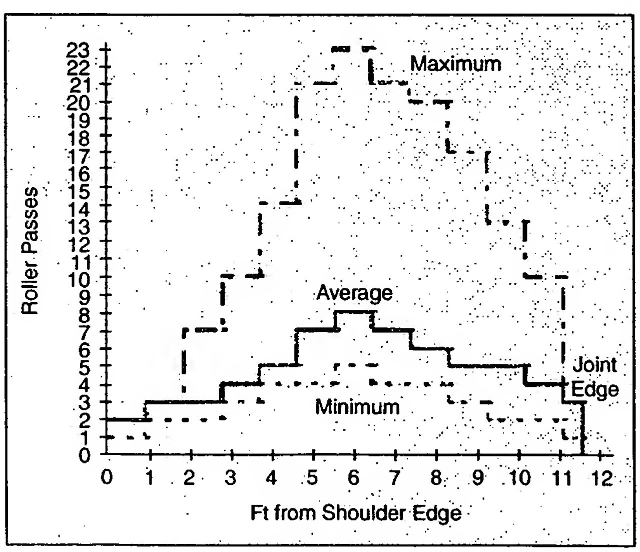

Figure 1. Observations made at locations in a stretch of pavement.

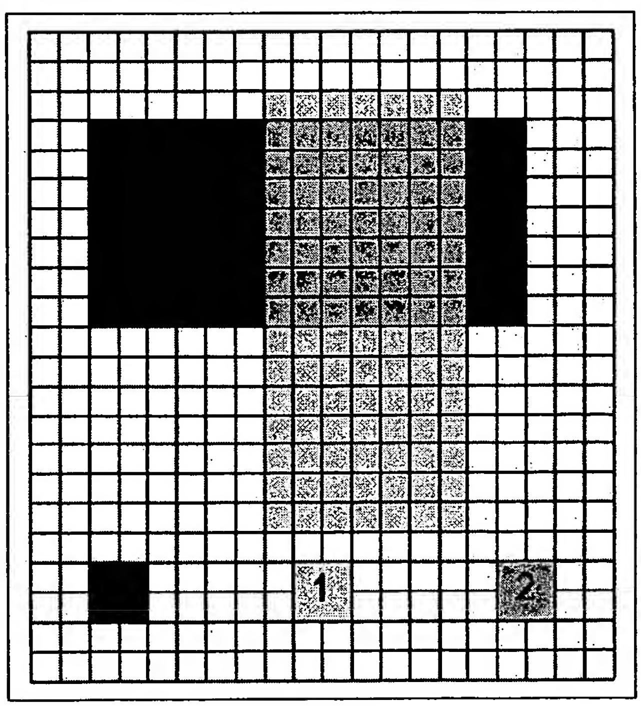

Figure 2. Raster processing of polygons.

and have been one of the two major obstacles in developing a low-cost solution for this problem.

However, new single-frequency devices that use both GPS and the Russian GPS system (GLONASS) have been developed. Using both systems in position determination allows positional accuracies similar to dual frequency devices at about half the cost.

Work to Date

There have been numerous efforts to develop automated methods for the quality control of pavement compaction. Previous research includes

- the Compaction Documentation System (CDS) [8]
- the Compactor Tracking System [9]
- MACC [10], [11], using a laser positioning system
- the vector-based Compaction Tracking System [12].

The CDS system was a system of monitoring the compaction process where data, such as lane change, direction change, number of passes, layer number, and start and stop of the compactor, are entered manually by the operator during the process. Since there is no sensor to identify the orientation and position of moving the compactor, the operator must follow the moving path, which is decided previously. The compactor tracking system (CTS) system [9] used post processing of positional data and a raster-based approach for data manipulation. The MACC system, developed in France, is a prototype operator aiding system for compactors that displays a real-time 2-D colored map of the compaction pattern. It has a similar concept to the CTS, but uses a laser system for positioning (CAPSY), while the position data for the CTS is given by GPS.

Both CAPSY and GPS determine positions using trigonometric principles that need a number of fixed and known points. CAPSY requires a number of reflectors as the known points and uses a rotating laser to detect the distances from the reflector to the system. The laser's range limits the overall range of CAPSY, and the cost is very high, however, accuracy is excellent. The MACC and CTS systems also use different methods for calculating the number of coverages.

Proposed System Architecture

In asphalt compaction, it is customary to use more than one compactor behind the paver. The first compactor, named the breakdown roller, is used to create the initial compacted surface. While compacting with the breakdown roller achieves most of the final asphalt density, the roadway surface is not as smooth as it can be. To improve roadway surface smoothness, the initial breakdown roller may be followed by another breakdown roller, or by a pneumatic roller followed by a finish roller.

Therefore, the proposed system must not only be capable of tracking multiple compactors, it must also be able to display to all compactor operators the total number of coverages achieved over the roadway surface.

The system's architecture is composed of positioning devices, hardware, and software. For positioning, the researchers selected high-accuracy, real-time kinematic (RTK) GPS devices with two distance root mean square (DRMS) accuracy of 1 cm. (2 DRMS is the radius of the circle representing 95% of static positions). While it is conceivable that lower accuracy devices may be sufficient, it was decided to initially use higher accuracy devices to prove the concept and reduce the total cost of the system.

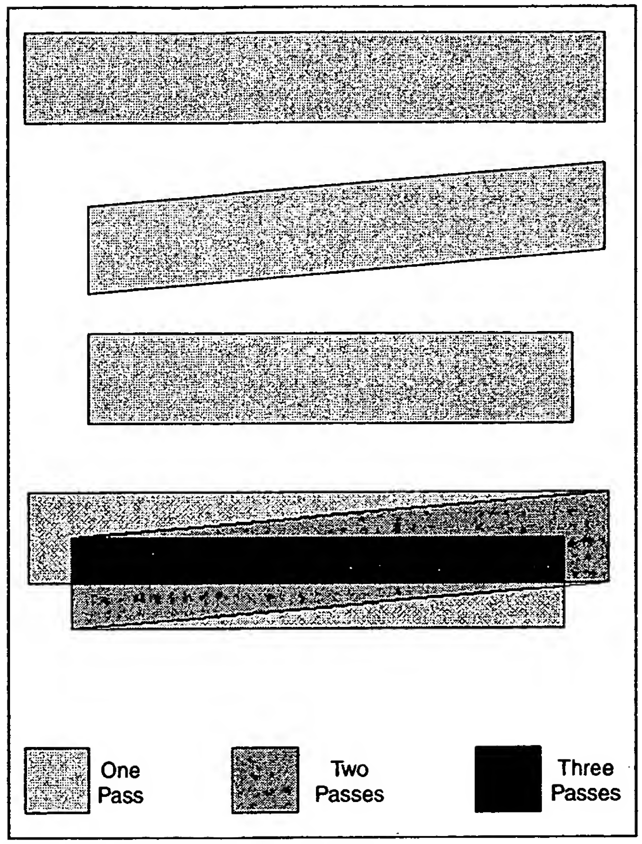

Figure 3. Vector processing of polygons.

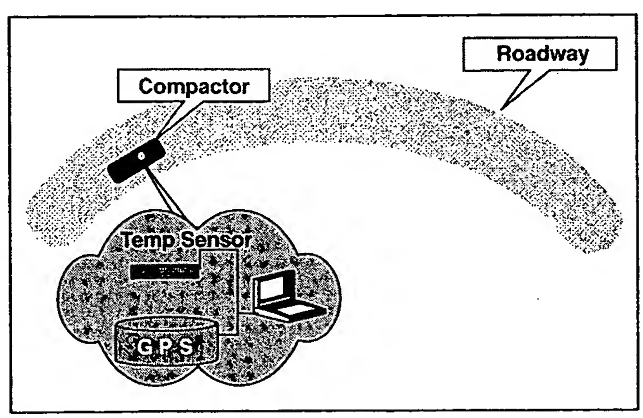

Figure 4. CTS-II architecture.

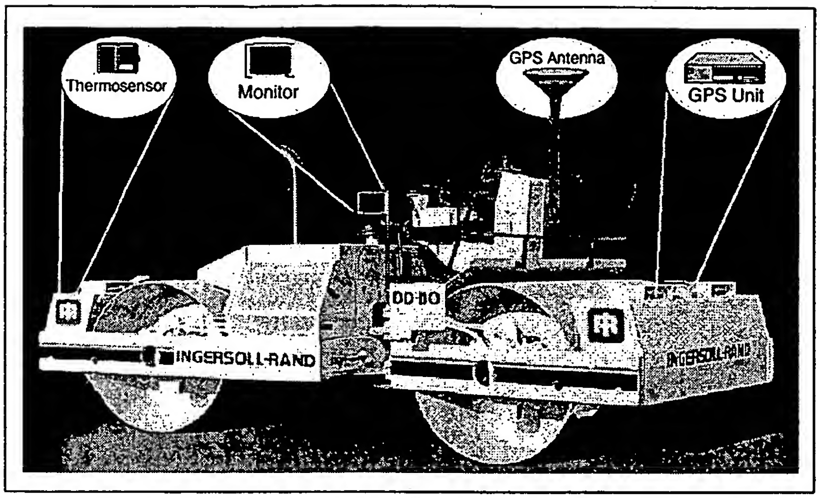

Figure 5. Compaction equipment with proposed hardware.

done by contractors. It also provides conclusive documentation for claims to substantiate if the work was done according to the quality control plan.

The software is used to develop the coverages developed by the compactors. There are two methods that can be used. The first is based on image-processing technology, where images of polygons are "rasterized," and cell values at each location on the roadway are accumulated to develop the total number of coverages (Fig. 2). The second method for processing these polygons uses vector and polygon topology to achieve this result. In this case, intersection polygons are calculated and displayed with a color code corresponding to the number of coverages (Fig. 3).

For the hardware architecture, the researchers selected simple inexpensive and diskless computers on each compactor. Each computer interfaces with the GPS device onboard its compactor and sends the compactor's position to a remote computer (base station) on the site. The base station assembles the coverages from all compactors and broadcasts the final coverage to all compactors.

This design allows multiple compactors to be tracked, as the main processing chores are done on the base station, thus eliminating the need for expensive computers to be installed on each compactor. This architecture also allows the simultaneous creation of an independent record of the compaction process that can be used by the roadway's owner.

This approach provides a record that serves as a detailed and complete history of areas covered by the compactor that cannot be obtained by other tests or devices. This configuration provides an independent data gathering mechanism that can be used by owners and inspectors to substantiate coverages

In a raster-based system, coverage files are stored as a cluster of pixels, each with a color or number corresponding to the number of coverages. In a vector-based system, coverages are stored as a set of locations corresponding to the polygons developed by the compactor footprint. In the system developed for CTS, a raster-based system was used, whereas CTS-II utilized a vector-based system.

After a reasonable number of points are acquired, there is no degradation of performance from raster processing. However, in vector processing, unless data smoothing is employed, performance will continue to degrade as more points are added.

Compaction Tracking System (CTS-II)

For the last three years, with collaboration with researchers at Penn State University, the author developed two early prototypes (CTS and CTS-II) [9], [12] to prove the feasibility of the proposed system, along with evaluating the suitability of high-accuracy GPS devices for this application. Figs. 4 and 5 show the implementation of an earlier system. This system was

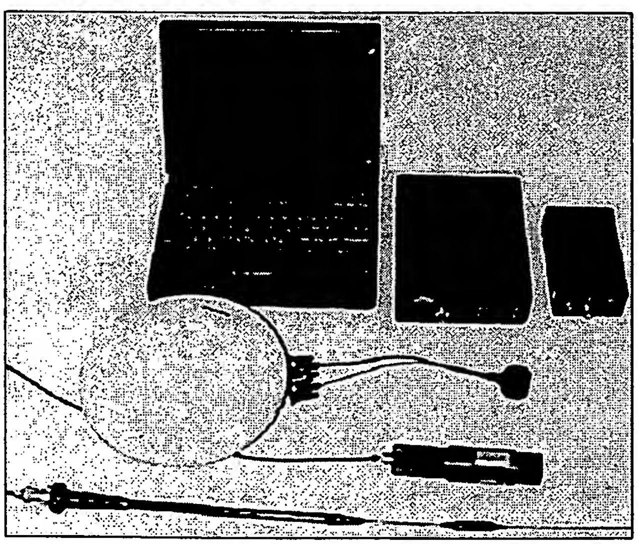

Figure 6. Hardware used for CTS-II.

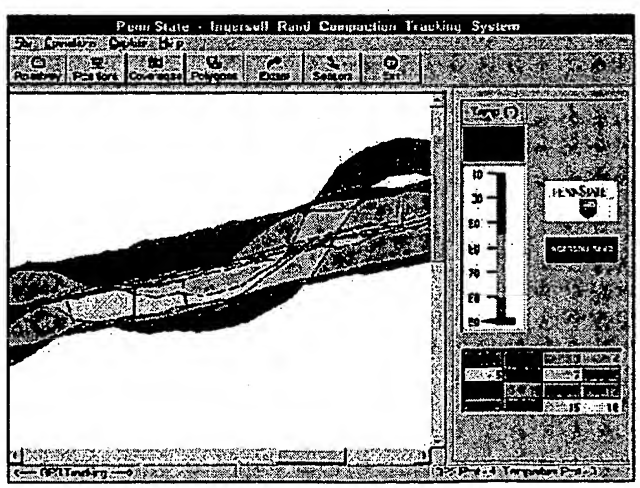

Figure 7. CTS-II user interface.

designed to track a single compactor, and all calculations were done onboard the compactor. A GPS-based positioning device is placed on the compactor.

The hardware used for CTS-II is shown in Fig. 6, consisting of an Ashtech GG24 receiver, along with radios (for DGPS), a notebook, and an infrared (IR) temperature sensor to measure the asphalt temperature.

The CTS-II software developed is shown in Fig. 7. The software processed the position data, and the output coverages are also shown in Fig. 7, where different colors represent a different number of passes. In this case, a compactor operator may be instructed to roll over the pavement until the screen shows "green," indicating that the correct number of passes has been achieved. These results matched (within 5%) the coverages observed, thus proving the viability of the prototype.

Operation of the System

To develop a graphical depiction of the number of passes executed over the length of a roadway, CTS-II implemented an algorithm developed during the CTS project phase [9]. The algorithm starts from corrected locations supplied by the GPS device on the compactor. With a compactor's drum width and GPS device location as input, the footprint of the compactor is determined. By continuously connecting the front edge of the compactor, a polygon is derived that depicts the compacted area during this elapsed time.

In the development of CTS and CTS-II, this algorithm was tested and refined with better methods to terminate polygons in case the compactor changes direction. At this stage, the system has a number of overlapping polygons. To find the exact number of passes at each point in the roadway, these polygons are processed to find the number of passes over each point (Fig. 8).

CTS-II System Challenges

CTS-II suffers from the following problems:

- As mentioned earlier, it is customary in pavement jobs to use more than one compactor, with the second unit for finishing the asphalt surface. Currently, CTS-II cannot handle data from multiple compactors.
- Computations are carried out using a notebook on the compactor. This requires a relatively fast processor and a hard disk on the compactor, requiring extensive provisions for shock mounting that substantially increase cost.
- Performance is too slow. This is due mainly to the large number of "sliver" polygons created after a large number of coverages is achieved. This effect can only be mitigated if a "dissolve" operation is used, where sliver polygons with the same coverage are dissolved into one larger polygon, eliminating the need to store and transmit this unneeded geometry (Fig. 9).

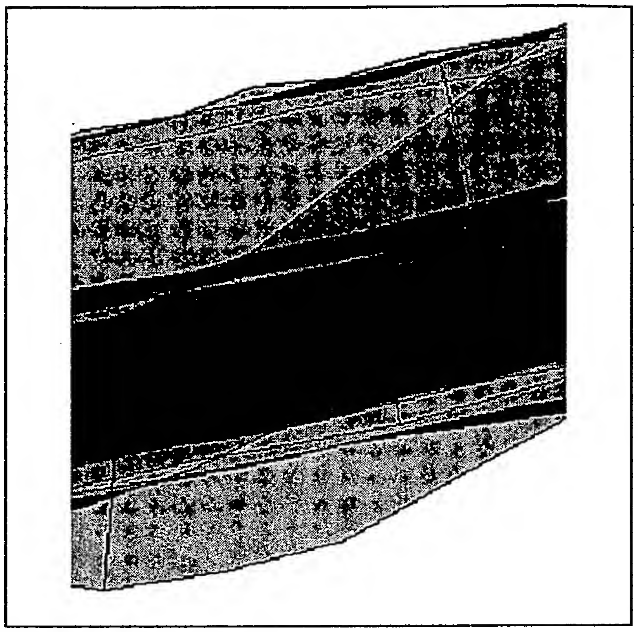

Figure 8. Output coverages.

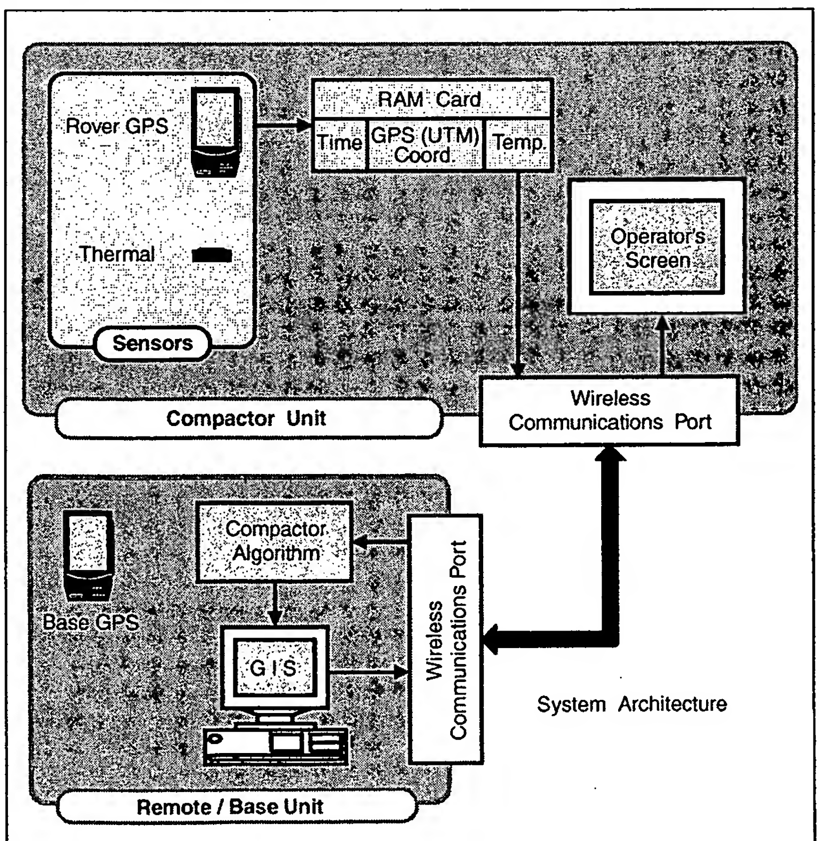

Figure 9. CTS-III architecture.

- It is not known whether vector processing is truly superior to raster processing. As we mentioned earlier, raster processing is faster to compute but slower to transfer in a wireless system. Vector processing produces smaller files but requires more time to compute.

This design allows multiple compactors to be tracked, as the main processing is done on the base station, thus eliminating the need for expensive computers to be installed on each compactor.

Compaction Tracking System (CTS-III), Latest Developments

To solve the problems listed above, the research team at the University of Central Florida developed a new version of the Compaction Tracking System (CTS-III) [13]. This system is capable of tracking up to four compactors simultaneously, with little degradation in performance shown in simulated tests.

The system consists of a Symbol Technologies diskless color workstation, running *Microsoft Windows*, on each compactor. Each workstation sends its vehicle's position, via Symbol's Technology Spectrum 24 (2.4 GHz) wireless network, to the base station using a TCP/IP-based protocol. The new system architecture is shown in Fig. 9.

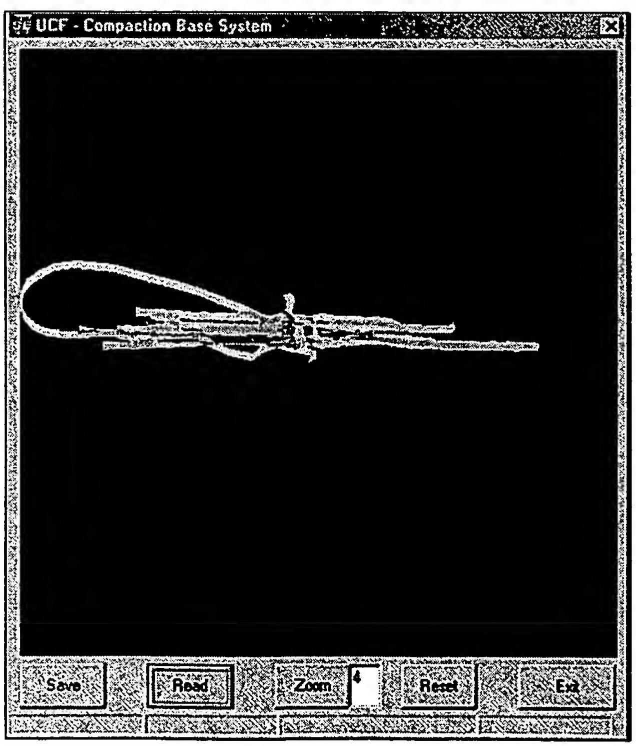

Figure 10. *CTS-III user interface (base).*

The base station receives positions from all compactors. Using the algorithms discussed earlier, the footprint of each compactor is deduced, and the output coverage is developed through a raster "overlay" operation. All compactor tracks are overlaid in this manner, and an output-coverages file is produced and broadcast back to all compactors. This provides a real-time color-coded display of all passes done by all compactors for each compactor operator.

A major challenge in the development of the new system was overcoming the performance degradation of vector-based processing, as described before. To solve this problem, the researchers used a compressed, lossless, raster-based format, as opposed to the vector processing described before.

To allow the compactors to accomplish their work while the asphalt is still within correct temperature ranges, the roadway being paved is broken into sections that correspond roughly to the distance being paved behind the paver. Each section is stored in a raster file.

There as several image compression methods available. For the requirements of this research, the stored image had to be extremely small in size to reduce transmission bottlenecks. Also, the image stored must retain the original colors as each color represents a specific number of passes. Some image compression schemes are "lossy," which means that some of the original colors may be lost when the image is compressed. An example is the popular "jpg" format used extensively on the Internet. While jpg files are small in size, this format was intended for displaying pictures and deemed not suitable for this application.

The image format selected has a maximum of 16 colors representing the various passes. This allows sufficient representation of the number of passes, while reducing the size of the file. Figs. 10 and 11 show the software developed for the application for the base station and compactors (rovers).

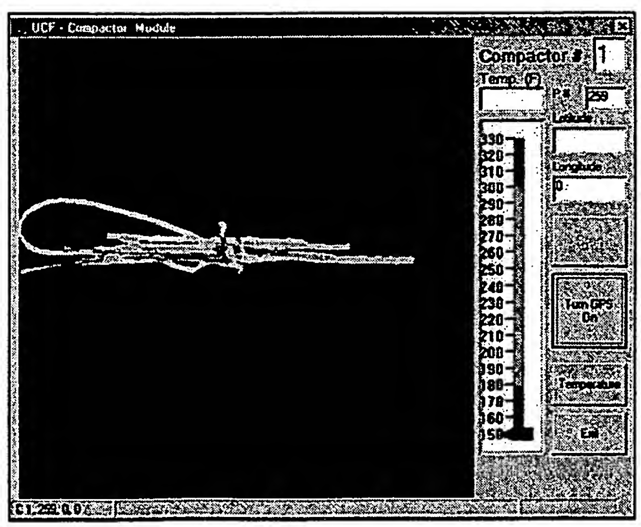

Figure 11. *CTS-III user interface (rover).*

Conclusion

This paper described research to develop a GPS-based automated quality control system for tracking pavement compaction. The research team has experimented with both vector and raster based algorithms and believe that the raster-based algorithm may be more efficient in this application. Simulated tests on CTS-III have been extremely encouraging, and the team continues to improve the system for testing. After the tests are completed, the researchers are confident that this technology can be fitted in existing compactors at a cost of about $10,000 per compactor, including GPS devices, radios, hardware, and software.

Acknowledgments

The author wishes to thank Penn State collaborators Dr. H. Randolph Thomas and Won-Seok Do for their contributions to this research. Also, the Ingersoll Rand Corporation and the Ben Franklin Partnership of Pennsylvania for sponsoring earlier research. Special thanks to Edmond Norse at Trimble Navigation Ltd. and to Dr. Frank van Digglen of Ashtech Inc. for their help and support. Also, thanks to Symbol Technologies for hardware grants in support of this research.

Keywords:

Asphalt compaction, compactors, GPS, tracking, vector, raster, superpave, wireless communications.

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